Memory tracking of the health state of Smart products in their lifecycle.

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International Conference
on Industrial Engineering and Systems Management
IESM'2013
October 28 - 30, 2013
RABAT - MOROCCO

Memory tracking of the health state of Smart products in their lifecycle

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Abstract :
PLM is a strategic approach to manage the product /equipment related information efficiently over the whole product lifecycle. To meet this target, a PLM system is developed in this study to track the status of a product/ equipment and its evolution and to analyze problems that may occur at any stage of its life cycle. This paper deals with the generation of an intelligent product that is capable of monitoring and capitalizing its own heath state during its whole life. An approach of knowledge capitalization was developed to construct a memory that identifies the health state of an equipment for its whole life. This memory is distributed into a short term memory located at the RFID tag that is associated with the equipment and a long term memory that capitalizes all the information concerning the equipment. This embedded memory is readable directly thanks to the RFID reader, and provides the information that helps the decision concerning the recycling or not of products/equipments.
*Key words: **P**roduct **L**ifecycle **M**anagement, Health state, smart product, traceability, Record memory*

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1 Introduction

Our work lies in the scope of **Product Lifecycle Management (PLM),** which has as main aim the management of business processes and the associated data generated by events and actions along the product's lifecycle phases.

The product's lifecycle phase is composed of three principal phases; the Beginning of Life (BOL) including design and manufacturing, the Middle of Life (MOL) including usage and maintenance and End of Life (EOL) including recycling, disposal or other options [6].

Sustainability on social, environmental and economic level is strongly dependent on the availability of information about the product throughout its lifecycle.

This study is a part of our research work realized in the European project SMAC, the project is about the enhancement of sustained performance of products (complex technical products or equipments) using tracking systems and modern techniques of maintenance throughout its whole lifecycle.

The context of our work emphasizes on the phase MOL in the tracking of the health state of an equipment, its maintenance in order to decide whether the component in the phase EOL is reusable or not for another equipment of the same family. In fact, some comapnies having a fleet of aging machines propose the ability to recycle the components that are not no longer used in the market, in order to avoid throwing away their machinery.

The decision about whether recycling or not this component (product) depends on its past and actual health state and the maintenance it received. This information must accessible easily and available on the component in order to be able to make a decision about the reutilization of the component even on shelf.

PLM is a strategic approach to manage the product related information efficiently over the whole product lifecycle. To meet this target, a PLM system should be able to track the status of a product and its evolution and to analyze problems that may occur at any stage of its life cycle. In this context it appears as an essential component of the information system. Kiritsis defines a Closed-Loop Product Lifecycle Management (PLM) models [6] in the European project PROMISE, the first project which had developed an integrated infrastructure for the exchange and processing of product lifecycle management data throughout all lifecycle phases.

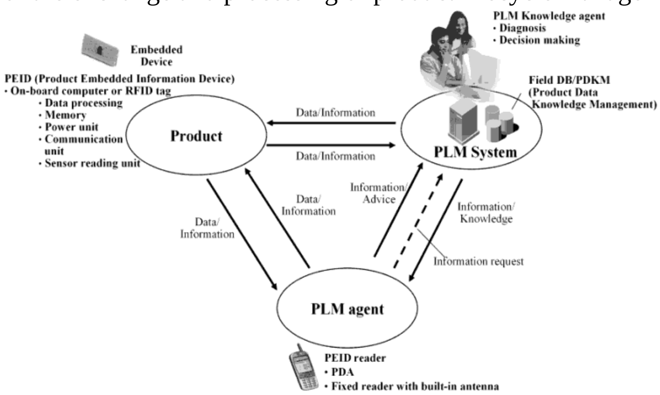

Fig. 1. The closed-loop Product Lifecycle Management concept [6]

Traceability is an essential element with regards to the capitalization of various evolutions taking place on the product.

A key requirement for the efficiency of PLM is the traceability of data, information and knowledge related to the product in order to enhance information sharing, use of prior knowledge to help actors to take the right decision to each phase of the lifecycle.

Beyond managing the lifecycle, it can contribute to knowledge capitalization.

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The aim of our study is to track the health state of equipments during the life cycle of the product, with the target to reuse this equipment. To realize the goal of this project our approach is to make the product smart. It is a very promising target field of using information integration of elements of today's PLM systems and models**..**

Our ambition is to create an intelligent equipment that contains within it the information needed to obtain a knowledge base that allows to decide whether it can be reused or not.

Thanks to the new material technologies such as sensor networks RFID1, les PDA2, glasses or smartphones headsets, we ease and simplify the task of users in the powering and information consulting process by establishing a system that allows the user to connect remotely to the system of information where the equipment is integrated (PLM system).

In order to make this component and/or system intelligent, we propose to associate to it a memory that traces its life thanks to a PLM system. The PLM system assures the capitalization of the knowledge during the life of the component, in order to provide a useful knowledge that helps the decision making about the future use of the component. So, in this study we will develop an approach of knowledge capitalization in section 3 after having defined what an intelligent component is in section 2.

Section 4 will be devoted to the description of knowledge information and memories that serve to ensure the tracking of the health state of the component throughout its lifecycle. Finally we will prove the feasibility of this method by applying it to two components of an industrial system of supervised pallets transfer.

2 SMART PRODUCT: AN ARCHITECTURE OF PLM SYSTEM

2.1 SMART PRODUCT

Different definitions of smart products are listed by Kiritsis in [7]. He defines an intelligent product as a product system which contains sensing, memory, data processing, reasoning and communication capabilities at four intelligence levels.

Intelligence Level 1: physical products without any embedded system (device or software)
Intelligence Level 2: physical products with embedded simple sensors.
Intelligence Level 3: physical products with embedded sensors, memory and data processing capabilities
Intelligence Level 4: physical products with Product Embedded Information Devices (PEID)

The intelligent product that we propose, does not belong exactly to these categories, because it does not possess sensors and it is not that complex but it includes an embedded memory and some of the characteristics of levels 3 and 4 because it capable of recording its related information in a personal memory and of accessing remotely the reasoning.
When it comes to monitor a critical component of a base, we must take the definition of Mc Farlane. McFarlane et al. [2] define an Intelligent Product as a physical and information based representation of a product: the physical product and the information based representation of the product are stored in the database, and the intelligence is provided by the decision making agent. The connection between the physical product and the information based representation is made using a tag and a reader.
an Intelligent Product has the following properties :

1. Possesses a unique identification.
2. Is capable of communicating effectively with its environment.
3. Can retain or store data about itself.
4. Deploys a language to display its features, production requirements, etc.
5. Is capable of participating in or making decisions relevant to its own destiny.

2.2 Closed-Loop Product Lifecycle Management (PLM) models

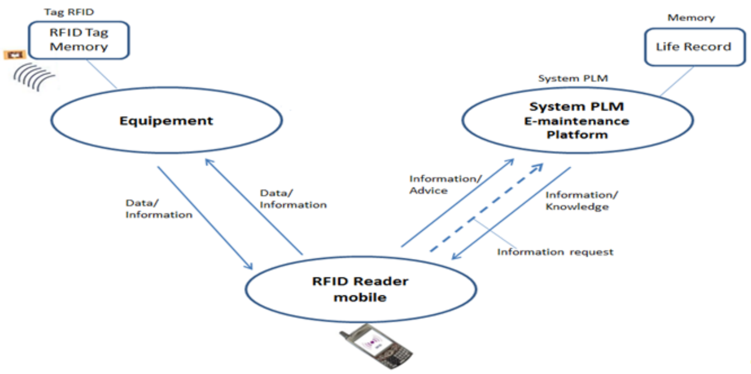

Fig. 2. Closed loop Model of the System PLM

1 RFID : Radio Frequency IDentifier
2 PDA : Personal Digital Assistant

To make a component intelligent and for it to possess the properties defined by MC Farlane, we propose to establish the Closed-Loop Product Lifecycle Management (PLM) models that are illustrated in figure 2.

To the critical components of an equipment to be tracked we associate

- An RFID tag with a unique identifier and that contains a minimal memory that records the essential information and permits the component to connect.
- **The additional element is that identification and communication capabilities are now added to the product characteristics, thanks to RFID, NFC (Near Field Communication)**
- An access by mobile agent (mobile RFID reader) to the PLM system and to a memory " vital card "
- A PLM system allowing the assurance of the knowledge capitalization concerning this equipment.

In order to favor knowledge reuse our objective is to create a corporate memory for a company specialized in maintenance services. This memory is acquired by the knowledge capitalization process. The knowledge is "alive" and evolves in the knowledge management.

The corporate memory is composed of 2 memories associated to critical components.

RFID Tag Memory: With the help of a mobile reader available thanks to the NFIS technology, we can read locally the tag identifier and the content of its memory "short term memory". The equipment is able to provide a minimum of information about its health sate: if for example the information about its routine maintenance is updated then this memory is the equivalent of a health booklet of that specific equipment.

LIFE RECORD: In a second stage we have the possibility to connect, via the network to the platform of e-maintenance and more specifically to the capitalized knowledge of the equipment section: "under its health's file": obtaining thus, all the information concerning the equipment model, its failures and the undergone interventions.

We will define the capitalization of knowledge approach and the reutilization of knowledge about the health state of a critical component.

3 Approach of Knowledge Capitalization

To ensure the traceability of information and to permit the knowledge capitalization throughout the life of equipments, we will follow the approach of knowledge management of Grundstein [3] illustrated in figure 1. The mentioned approach consists of 4 phases

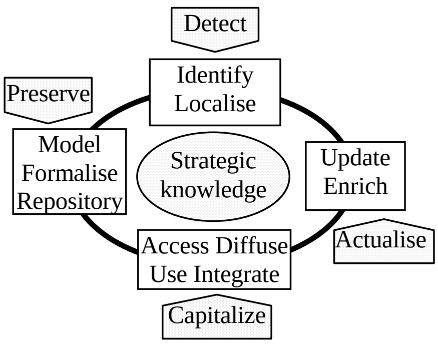

Fig.3. Cycle of knowledge capitalization [3].

The fig3 proposed by Michel Grundstein illustrates the process cycle of knowledge capitalization. Our previous works we associate to each phase of this process the methods we used in the field of e-maintenance, as rasovska [9]. The cycle highlights 4 phases.

Detection of information: the practice of maintenance experts was observed in their activity of industrial plant related on the each maintenance event. Events created by the planning of systematic maintenance, events caused by failure and diagnostic task, events produced to do intervention procedure. Observations relatives at the health state of the equipment.

Preservation of knowledge: Among the three approaches of corporate memory construction, we have chosen to formalize our knowledge model by an expertise domain ontology of maintenance developed by H. Karray and al [5].

Capitalization of knowledge: the capitalization is done by a platform of e-maintenance used as a support for information diffusion. Web services were developed in order to relate knowledge acquisition with the access to expertise, and to store information in memory.

Update of knowledge: this step is ensured by the Life record service of the platform, described later in the paper. The access to the memory is opened to all maintenance actors, to consult on the other hand modifications of the life record memory.

3.1 Detection of Crucial Information

In this work we are particularly interested by the operations of equipment maintenance and by the tracking of the health state of an equipment and its maintenance throughout the operating phase of its lifecycle (PLM). We are also interested by the capitalization of this information in a technical memory.

In order to ensure the tracking of an equipment throughout its lifecycle and to describe the state of an equipment during its "operating" phase we must identify the type of data in relation to the functioning mode, which can be either normal, degraded or failing, and to the operating mode. The operating mode is related to the location of the equipment. We identified three operating modes:

- Operating: in this case, in addition to the production time, the placement of the equipment should be indicated in order to know the location of its functioning.
- In stock: an equipment in stock is an equipment that has the status of a replacement part
- In repair, the placement of the equipment may be the workshop or a stopping place.

The functioning mode of an equipment is its ability to accomplish a required function in conditions given at a time instant or during a time interval supposing that the external necessary results are furnished. There is different possible modes; normal, degraded and failing mode.

3.2 Modeling the Knowledge

To model the knowledge, we implement in a platform of e-maintenance the concepts defined in an ontology[3] of maintenance field with particularly the concept of life record [5] to which we will add the concept Tag RFID.

This ontology, associates to each equipment a memory card. The latter contains a set of operational modes and operating modes that are related to some periods each characterized by a beginning date and an end date.

The diagram of classes at figure 4 identifies the different system's objects modeled thus to set the links to be established between the different classes associated to the memory card.

[3] Ontology : a formal and explicit presentation of a common understanding of the concepts of the field and the relations between the concepts.

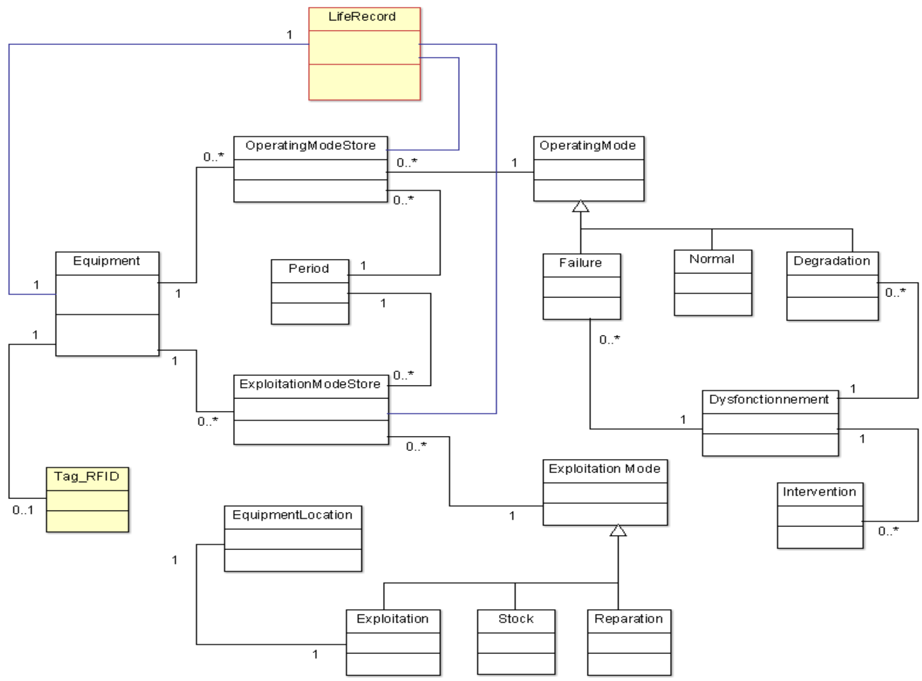

Fig.4. Diagram of the classes of the concepts related to the meùories

LifeRecord is a virtual memory that regroups the data concerning the lifecycle of an equipment. The attributes of the LifeRecord are some indicators that deduced from other attributes of the database. These attributes allow the understanding of the equipment's behavior in order to track its health state.
A TAG_RFID (Radio Frequency Identification) contains a minimal memory used to stock data associated to the equipment throughout its lifecycle.
An equipment has various operational and operating modes throughout the phase MOL of its lifecycle. An « OperatingModeStore » links the equipment to an operational mode during some period.
At each breakdown or degradation, a malfunctioning is associated to it? And for a malfunctioning, various interventions are possible.

3.3 Diffusion of Data and E-Maintenance Platform

The diffusion of data throughout the lifecycle of an equipment is done through a platform of e-maintenance. The information is collected, capitalized and stocked in a memory.

4 Life Record service and decision making about the reutilization of an equipement.

4.1 Web service of communication elaboration between memories (RFID and Life record)

The objective of this work is to implement, in the e-maintenance platform, some new intelligent services allowing the capitalization of information about an equipment during the middle phase of its lifecycle and the calculation of indicators to help deciding concerning the reutilization or not of an equipment.
Web services are becoming the technology of choice for realizing service-oriented architectures (SOAs). Web services simplify interoperability and, therefore, application integration [8].

Development of Java-based web services has come a long way since then. The annotation support introduced in java SE 5.0, and embraced by a wide variety of java technologies, makes creating and consuming Web services in Java is easy. The annotations @WebService and @WebMethod define the web service and methods witch support. This web service is based in an EJB stateless session Bean.

To ensure the follow-up of the equipment, we suggest the use of the technology of Radio frequency Identification tag (RFID tag). Also, the use of the Near Field Communication (NFC) technology facilitates Read/Write information in the RFID tag.

The idea is that an RFID Reader wants to call a method of the Web Service, it creates the HTTP request (with its complicated SOAP), sends it to the webserver providing the Web Service, waits for the reply, and then decodes the SOAP(Simple Object Access Protocol) that is returned by the Web Service.

The use of the Near Field Communication (NFC) technology facilitates Read/Write information in the Radio frequency Identification tag (RFID tag).

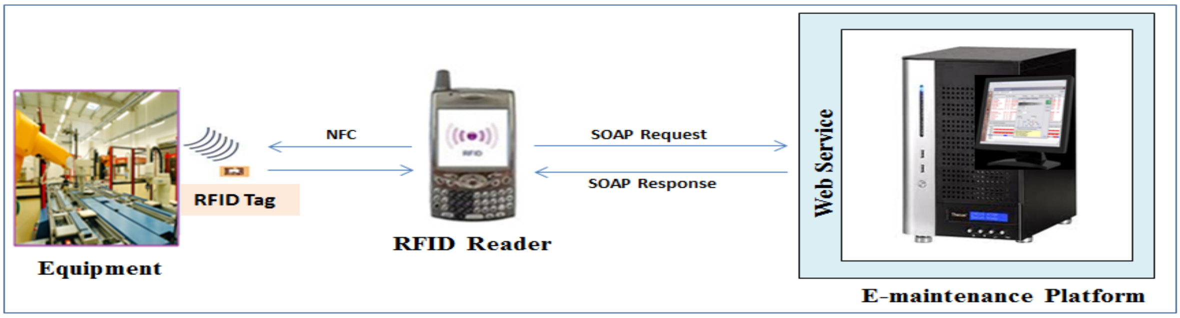

Fig. 5. Diagram of classes

The e-maintenance platform is based on the specifications J2EE[4]. The architecture J2EE presented by SUN defines a multi-level (or n- thirds) architecture for java distributed applications.

The architecture J2EE of the e-maintenance platform.

The used client is the navigator. It is a light client that ensures the accessibility to the platform.

The application's server used in the platform of e-maintenance is JBOSS[5]server.

The level persistence uses PostgreSQL as a system of management of relational object data (SGBDRO) in which the data of the platform are saved.

4.2 The information contained in the Life record and le RFID Tag.

- An immediate memory -that is named RFID in the diagram of sequence- that contains the last information about the health state of the equipment, the ongoing treatment (routine maintenance), the number of breakdowns. All this information can be read locally via a tablet available for users (FRID reader).

  The indicator saved in the tag are :
  *date of the first run; *the actual functioning mode ; *date of last maintenance ; *type of the last maintenance ;* number of breakdowns ; * functioning rate.
- A long term memory that capitalizes all the information concerning the maintenance and the health state of an equipment. The information contained in the Life Record of the platform is the following: * date of the first run; * the actual functioning mode ; * date of last maintenance ; * type of the last maintenance ; * list < breakdowns> (malfunctioning, period) ; * somme_functionnel_period hours ; * list <operating_mode> ; * list <exploitation_mode> ; * list <intervention>

[4] J2EE
[5] JBOSS

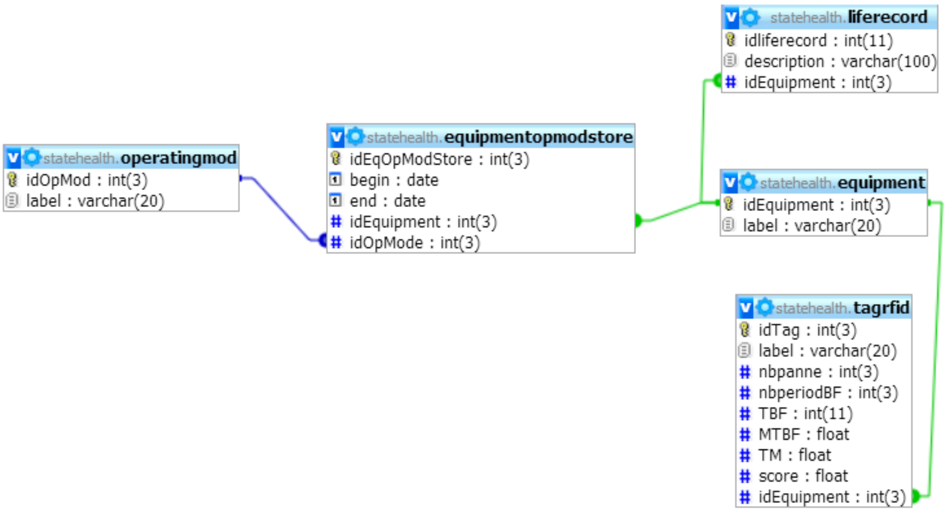

Fig.6. The memories and the associated information

4.3 RFID Tag service.

The consulting of memories from the equipment is done via the help of web service. We can see in figure 7 the different utilization scenarios of two memories.

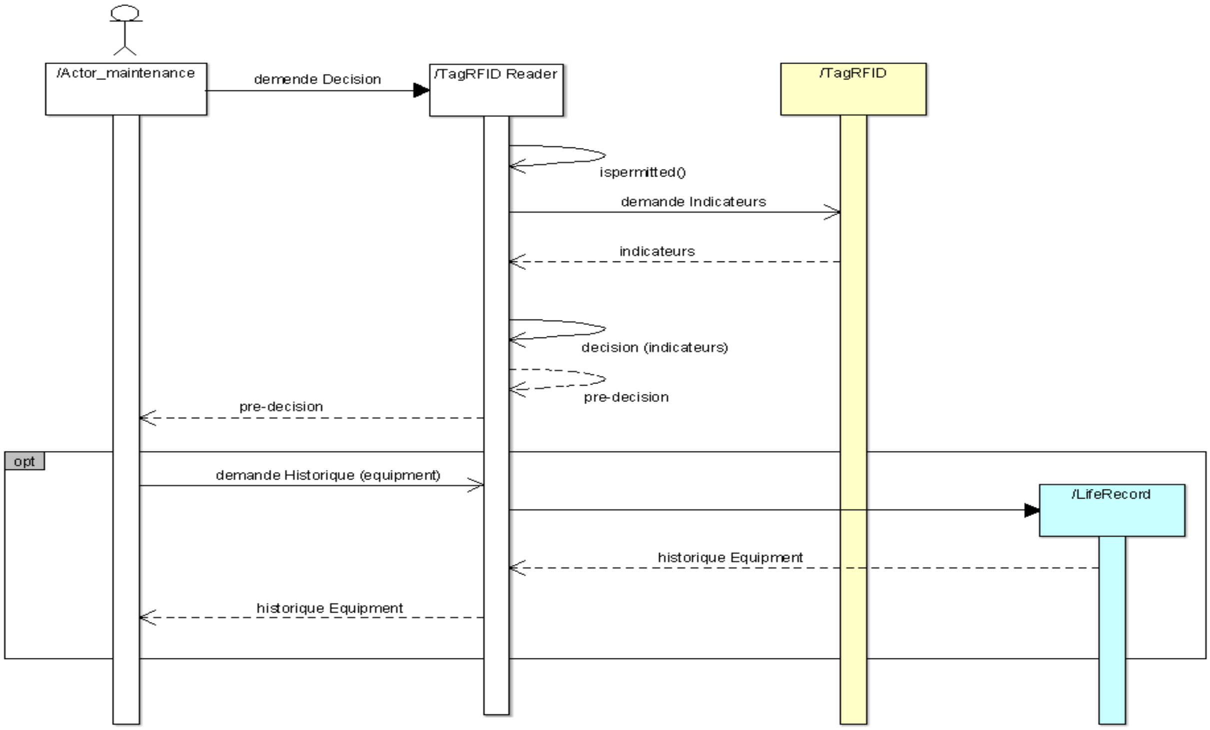

Figure 7. Diagram of the sequence of utilization of the TagRFID and the LifeRecord

4.4 Decision-making regarding the recycling equipment..

1° scenario : Reading of the RFIF tag Memory (sufficient RFID memory)
Objective: from the indicators of the Tag, decision making regarding the reutilization of an equipment.
If the number of breakdowns is higher than a predefined threshold $\boldsymbol{n_{threshold}}$ we throw away the equipmemt ;

In the opposite case, we are intersted by a score equal to $MTBF * TM > \boldsymbol{MTBF_{threshold}} \pm \Delta \boldsymbol{MTBF_{threshold}}$

TM= Rate of systematic maintenance (Taux de Maintenance Systématique) = number of performed systematic maintenance / number of scheduled systematic maintenance

Thus we take into account the maintenance performed on the equipment. If the rate is not good, we penalize MTBF by multiplying it to the ratio of maintenance. This may lead to invalid the reutilization of the equipment.

If the obtained value of the score= MTBF* TM is within the interval, we must consult the life record

2° scenario : We wish to consult the complete history of the component and to have the characteristics of the component.

4.4.1 Illustration

We take as an illustration hydraulic cylinders requiring some maintenance in order to continue functioning.

Let's consider the health state tracking of three cylinders. Tables 1 and 2 illustrate respectively the Life record and the RFID Tag (a line is associated to a tag).

$\boldsymbol{N_{threshold}}$ =3 and $\boldsymbol{MTBF_{threshold}}\,{}^{+}_{-}\,\Delta\boldsymbol{MTBF_{threshold}}$ =50 days${}^{+}_{-}\,\Delta$5.

Knowing that the cylinders run for cycles of 10 seconds and have a lifetime of 5 years. Thus from the indicators MTBF*TM we obtain

idTag	label	nbpanne	nbperiodBF	TBF	MTBF	TM	score	idEquipment
1	tag_verin1	3	3	102	34	0.8	27.2	1
2	tag_verin2	2	3	113	56.5	0.6	33.9	2
3	tag_verin3	2	3	103	51.5	1	51.5	3

Cylinder 1 encountered 3 breakdowns, hence i twill be thrown away. We notice in its liferecord that the third breakdown started on 04/15/2013.

Only cylinder 3 satisfies the condition of having the score higher than 55, hence it will be recycles, while cylinder 2 will be thrown away.

idliferecord	description	idEquipment
1	root@localhost Id with 1 normal started from 2013-01-01	1
2	root@localhost Id with 2 normal started from 2013-01-01	2
3	root@localhost Id with 3 normal started from 2013-01-01	3
4	root@localhostequipment 1 is failed at 2013-02-15	1
5	root@localhost Id with 1 normal started from 2013-02-16	1
6	root@localhostequipment 2 is failed at 2013-03-10	2
8	root@localhostequipment 3 is failed at 2013-03-10	3
9	root@localhost Id with 2 normal started from 2013-03-11	2
10	root@localhost Id with 3 normal started from 2013-03-11	3
11	root@localhostequipment 1 is failed at 2013-03-15	1
12	root@localhost Id with 1 normal started from 2013-03-16	1
13	root@localhostequipment 1 is failed at 2013-04-15	1
14	root@localhostequipment 3 is failed at 2013-04-15	3
15	root@localhostequipment 1 in theard failed and never used	1
18	root@localhost Id with 3 normal started from 2013-04-16	3
19	root@localhostequipment 2 is failed at 2013-04-25	2
20	root@localhost Id with 2 normal started from 2013-04-26	2

5 Conclusion.

In this study, we have proposed an approach to make the component and/or system intelligent, with the objective of monitoring its health state throughout its lifecycle and accessing easily all the time to the information of the equipment thanks to the RFID reader. We have proposed and established Closed-Loop Product Lifecycle Management (PLM) models that associate the technology of Radio frequency Identification tag, two local and remote memories and a platform of e-maintenance. The use of the Near Field Communication (NFC) technology facilitates Read/Write information in the RFID tag. The reader Tag permits the recovery of knowledge about the equipment. This knowledge is saved at an integrated memory of the e-maintenance platform.

An approach of the capitalization of knowledge is developed and it permits the construction of two memories, a life record and an RFID Tag. We have established the proposed architecture, the two memories and the exchange between them, all of this make the equipment intelligent.

First capitalization service and indicators calculations for the help of decision making were implemented. This service gives an indication about the possible reutilization of a component by relying on the information of the tracking of the equipment. We have proven the feasibility of this method on 3 examples illustrating the method.

We have the perspective of developing a nature size application.

References

[1] Aurélie Bissay, Philippe Pernelle, Arnaud Lefebvre, A. Bouras Démarche d'intégration des connaissances au système PLM published in "CIM'08, Sousse : Tunisia (2008)

[2] Duncan McFarlane, Sanjay Sarma, Jin Lung Chirn, C Y Wong, Kevin Ashton The intelligent product in manufacturing control and management Copyright © 2002 IFAC 15th Triennial World Congress, Barcelona, Spain

[3] Grundstein M., Développer un système à base de connaissances : un effort de coopération pour construire en commun un objet inconnu, CP2I, Paris, 1994

[4] Karray M.H., Chebel-Morello B., Zerhouni N. A Formal Ontology for Semantics in Maintenance Platforms, Applied Ontology Journal: Vol7, N°3, 2012 ISBN1570-5838 (Print) pp 269-310 IOS Press

[5] Mohamed Hedi Karray Contribution à la spécification et à l'élaboration d'une plateforme de maintenance orienté connaissances. Thèse, soutenue le 9 mars 2012

[6] Dimitris Kiritsis, Ahmed Bufardi, P Xirouchakis. Research issues on product lifecycle management and information tracking using smart embedded systems. Advanced Engineering Informatics 2003; 17 (3-4), pp. 189-202

[7] Dimitris Kiritsis Closed-loop PLM for intelligent products in the era of the Internet of things.. Computer-Aided Design 43 (2011) 479-501

[8] Hamid R.Motahari Nezhad and Boualem Benatallah Web Services Interoperability Specifications University of New South Wales Published by the IEEE Computer Society 0018-9162/06/$20.00 © 2006 IEEE

[9] Rasovska ,I, Chebel – Morello B, Zerhouni N A mix method of knowledge capitalization in maintenance in Journal of Intelligent Manufacturing Springer Netherlands ISSN0956-5515 (Print) Volume 19, Number 3 / juin 2008 pp 347-359